



## European Regional review of EUVL Activities

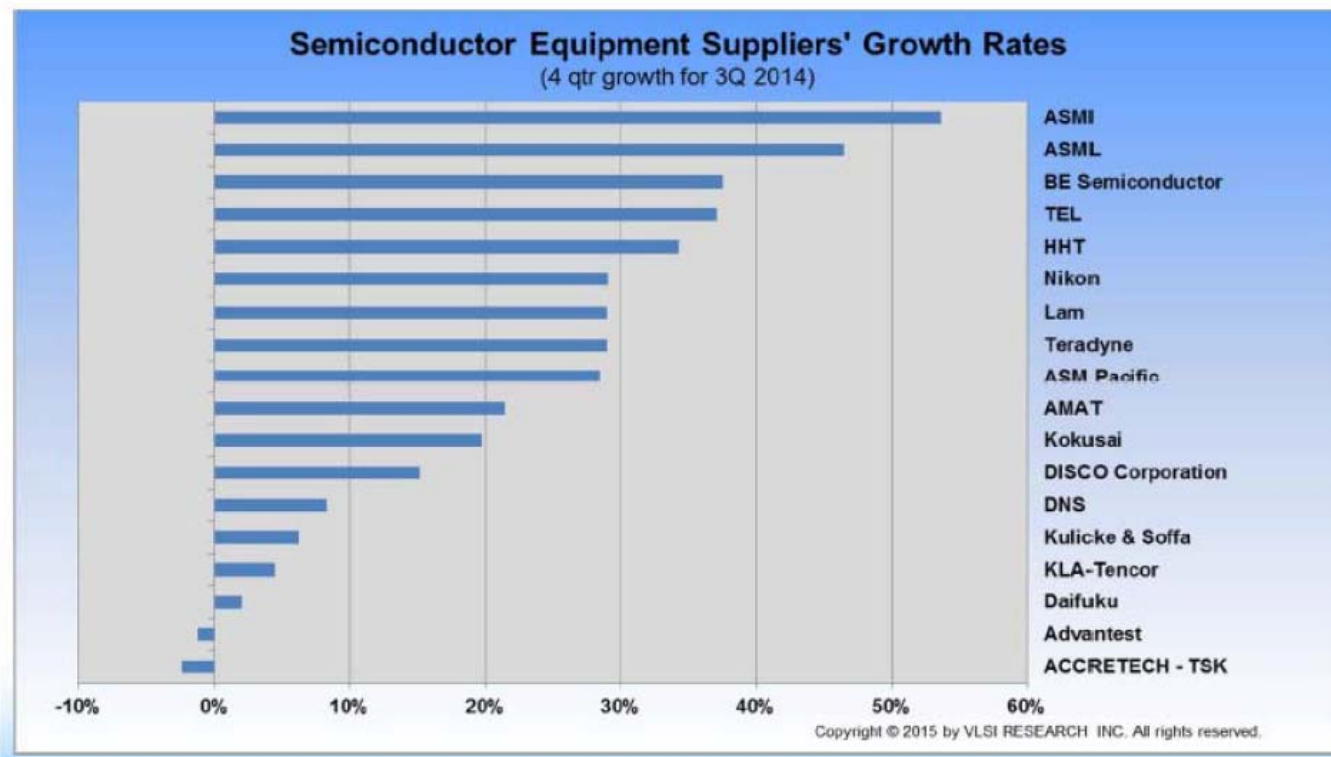
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*2015 International Workshop on EUVL  
June 15-19 2015, Maui Hawaii*

## Europeans fastest growing equipment suppliers!



Source: SEMI Market Overview, H. Kundert

## European Regional review - Contributions

- UCD
- ARCNL
- ASML
- Rigaku, University of Prague
- RWTH, ILT Aachen
- HiLASE
- University of Padova
- Zeiss
- optiXfab
- IMEC
- ETH Zurich
- PSI

## Dublin - UCD



- Short wavelength LPP emission spectroscopy on high-Z materials between 2 & 8 nm. Colliding plasma work ongoing with Nd:YAG & CO<sub>2</sub> laser irradiation.
- Working on an EUV reflectometer.
- Currently 10 students 3 postdocs & 5 staff.
- A lull in funding from Irish government sources.
- Collaborating with Utsunomiya University, CTU Prague, RWTH Aachen, Lanzhou University & Wuhan Inst. of Technology. Still in the EXTATIC Erasmus Mundus program.
- Water window (2 - 4 nm) source development progressing well.
- Hosting 2015 Source Workshop

## ARCNL - Amsterdam

### MISSION

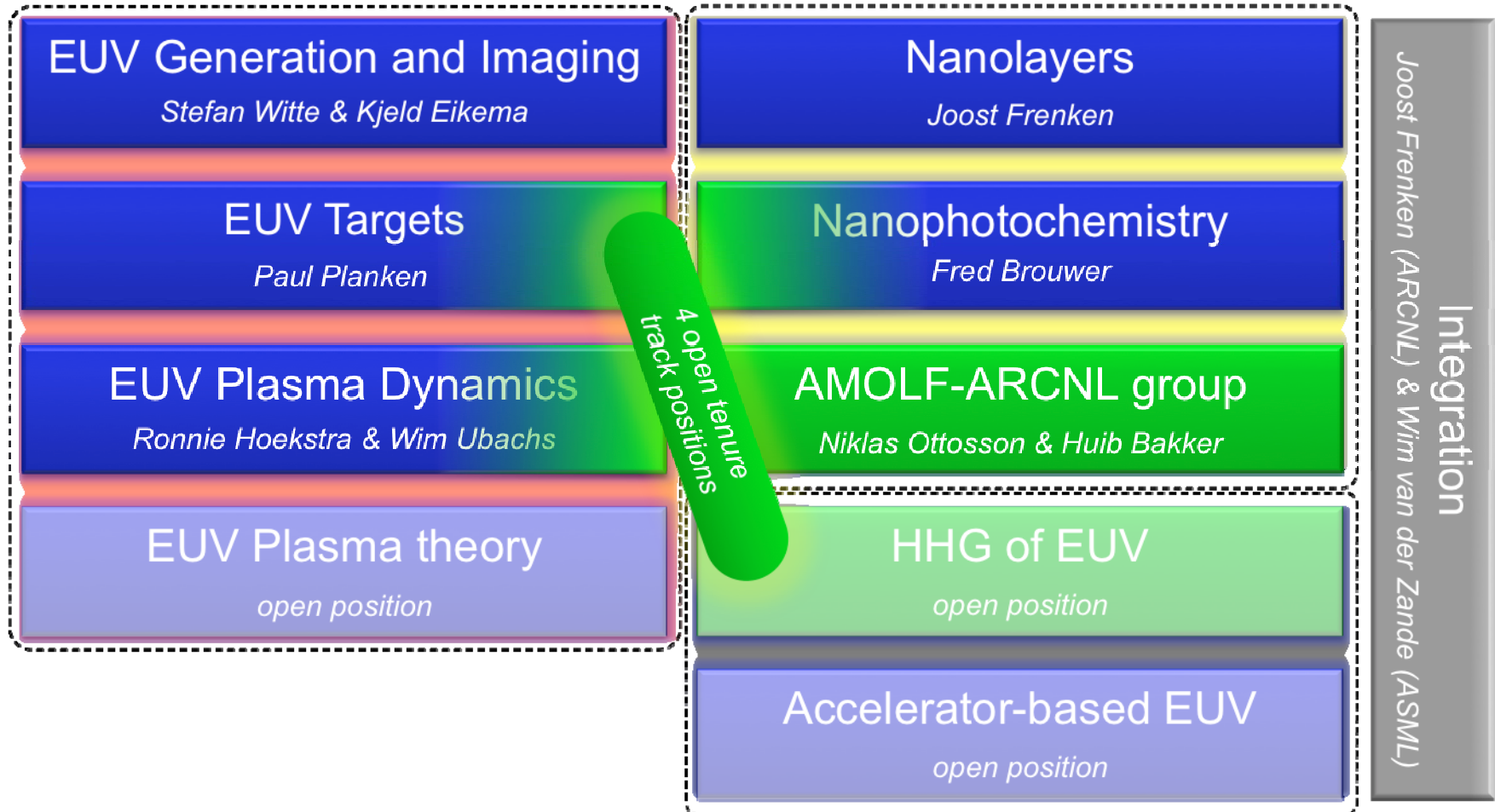
The research of ARCNL focuses on the fundamental physics that is involved in or related to current and future technologies that are or will be employed in the context of lithography and nanolithography, primarily for the semiconductor industry.

### Advanced Research Center for Nanolithography

- *Nucleus:* Instigated in 2013 by ASML, started in 2014
- *Launch:* 2014/2015 from FOM-Institute AMOLF
- *Partners:* ASML, FOM/NWO, UvA, VU
- *Form:* New type of public-private partnership (ARC)
- *Financial:* 50% base funds from ASML, 50% from the others
- *Size:* ~100 fte in 2016; now (June 2015) ~50
- *Style:* Managed as an FOM-institute
- *Location:* Science Park, Amsterdam



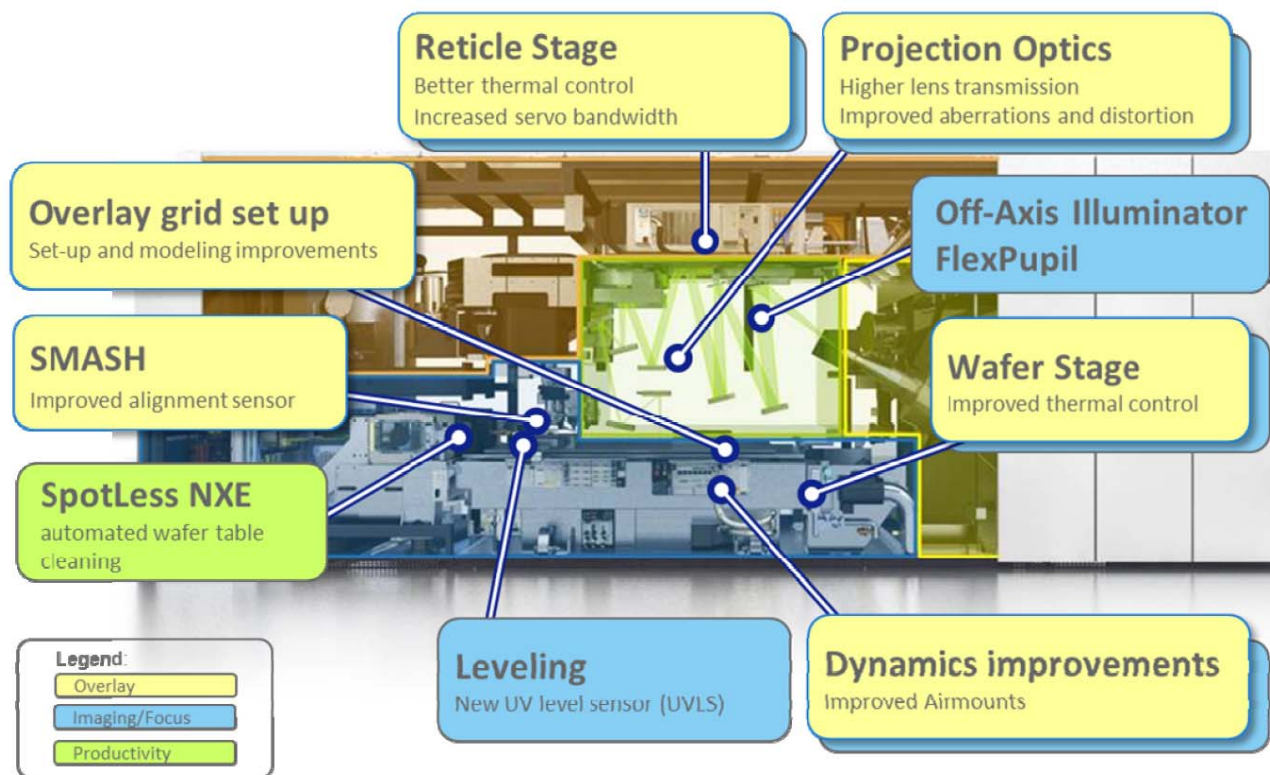
## ARCNL - Amsterdam





## ASML

- Multiple NXE:3300 are operational at customer sites with NA of 0.33
- Full Wafer Critical Dimension Uniformity (CDU) of 1.0-1.1 nm. No significant impact of pellicle.
- 80W configuration has proven capable of exposing 1,000 wafers per day
- Scanner defectivity keeps being reduced 10x each year.
- 4th generation EUV system NXE: 3350 is under qualification.



## Prague

### INSTITUTIONS



**Czech Technical University in Prague**



**Rigaku Innovative Technologies Europe, Czech Republic**

### ACTIVITIES

- Ultra-high resolution imaging in EUV and X-ray region (Rigaku)
- Precise metrology of EUV beams (Rigaku, CTU)
- Measurement of monocrystal scintillator quantum efficiency in EUV (CTU, CRYTUR)
- R&D of optics for novel EUV applications (CTU, Rigaku)
- CDP source upgrade (CTU)
- EUV generation in femtosecond LPP (CTU)

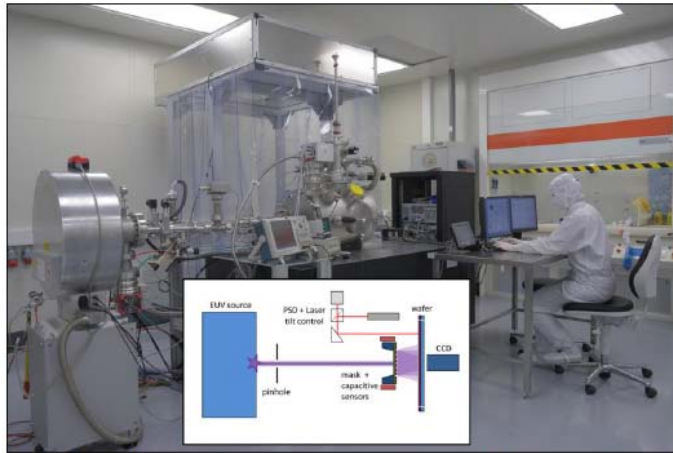
Efficient synergy: CTU – Acad. Of Sci. – CRYTUR - Rigaku

- LPP, DPP and HHG activities in Prague

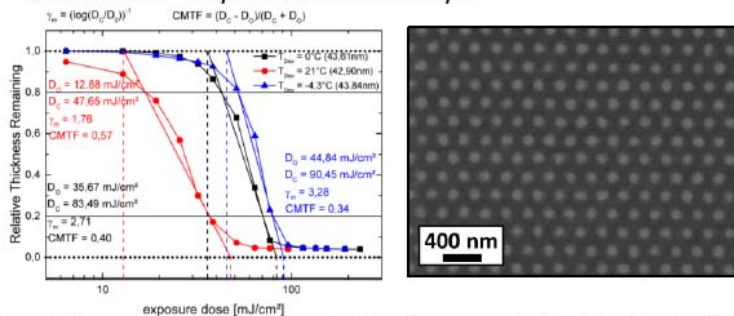


## RWTH, ILT - Aachen

## EUV – LET (Laboratory Exposure Tool)



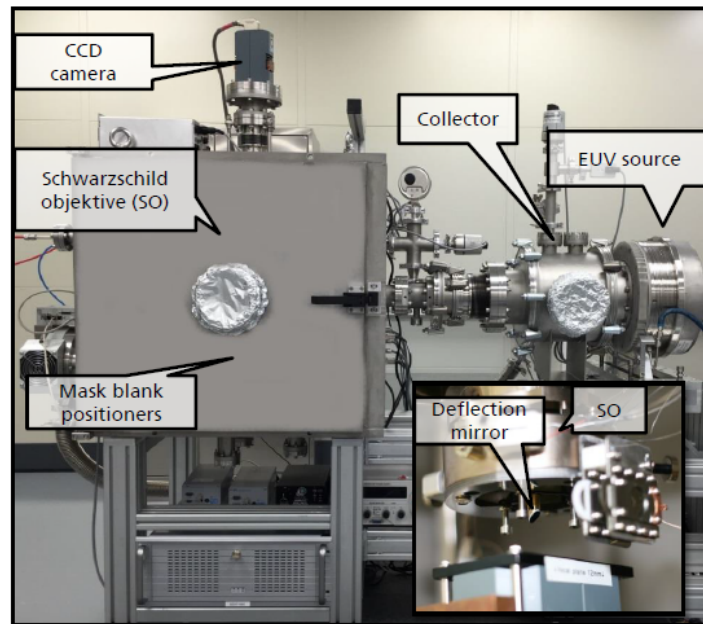
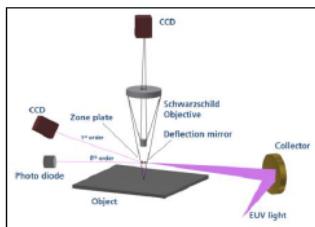
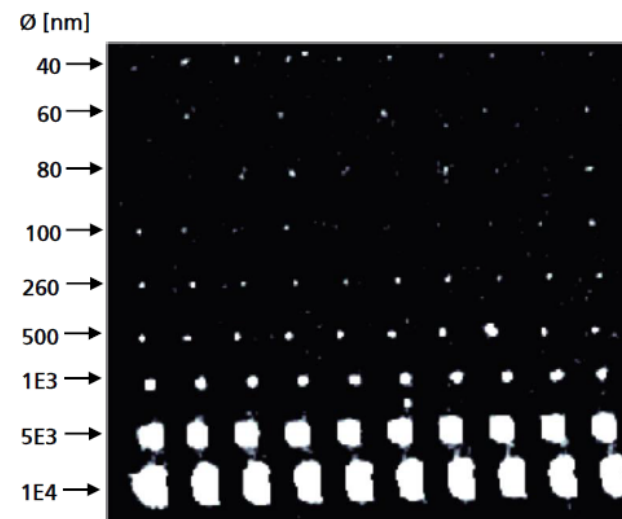
EUV-LET (Laboratory exposure tool). Inset: scheme of experimental setup.



- EUV patterning with proximity and Talbot interference lithography of samples up to  $\varnothing 100\text{mm}$ .
- Established mask technology with single exposure fields up to  $2 \times 2\text{mm}^2$ .
- Dose monitoring with multilayer tool at 13.5nm (2% b.w.) and broadband tool for 9.5nm to 18nm.
- High precision positioners on all axes (encoder resolution  $< 10\text{nm}$ ).
- Utilised for resist characterization and DSA prepatterning

RWTH, ILT - Aachen

## Actinic EUV mask black defect inspection

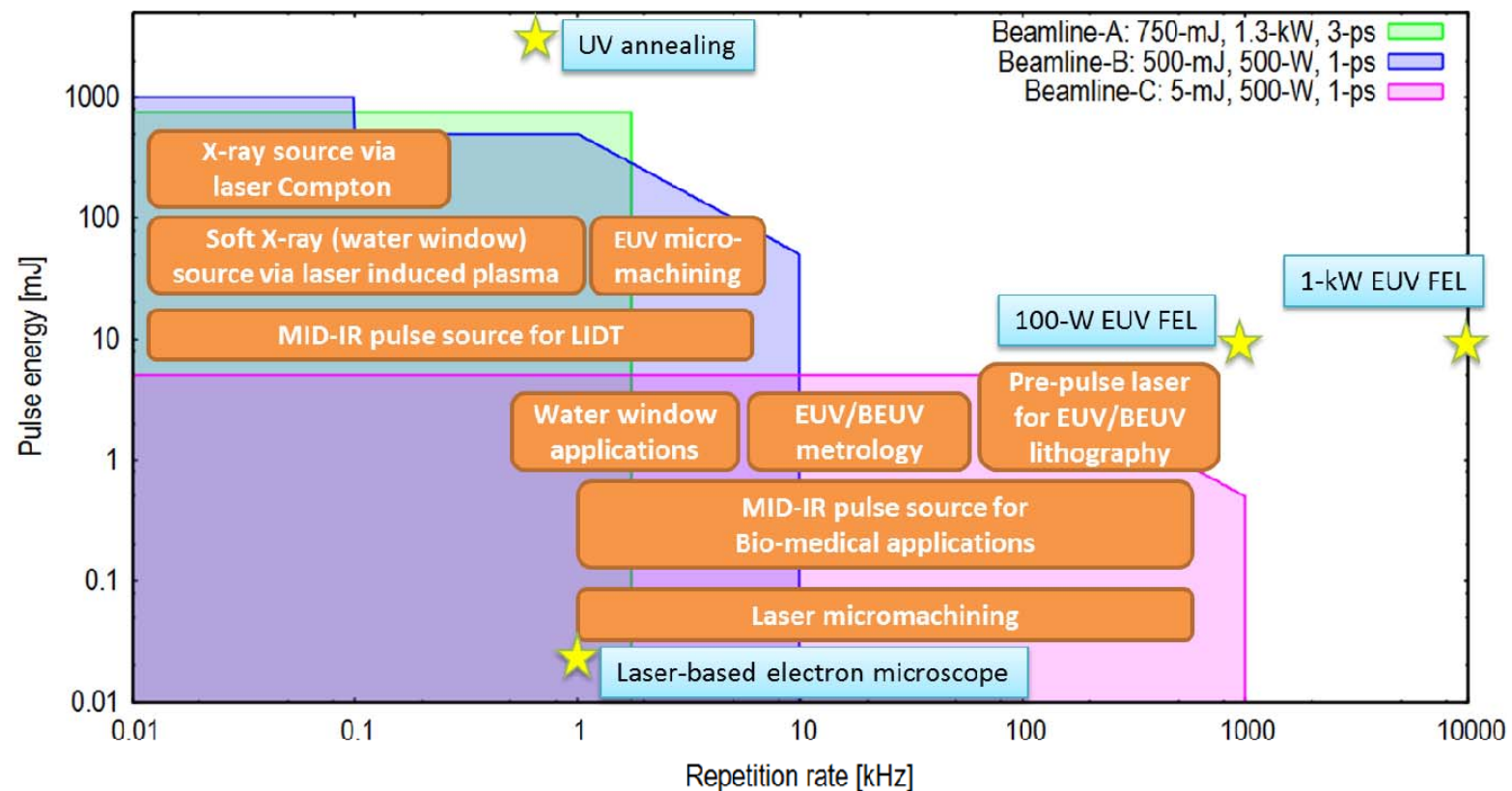
EUV Microscope,  $\sim 1.6 \text{ mJ/cm}^2$ 

- Dark-field EUV microscopy enables high throughput with sensitivity to small structures (down to 10 nm) and allows for detection of buried defects

& Metrology: Calibrated Dose Monitor, Pellicle Transmission Measurements, GI EUV reflectometer

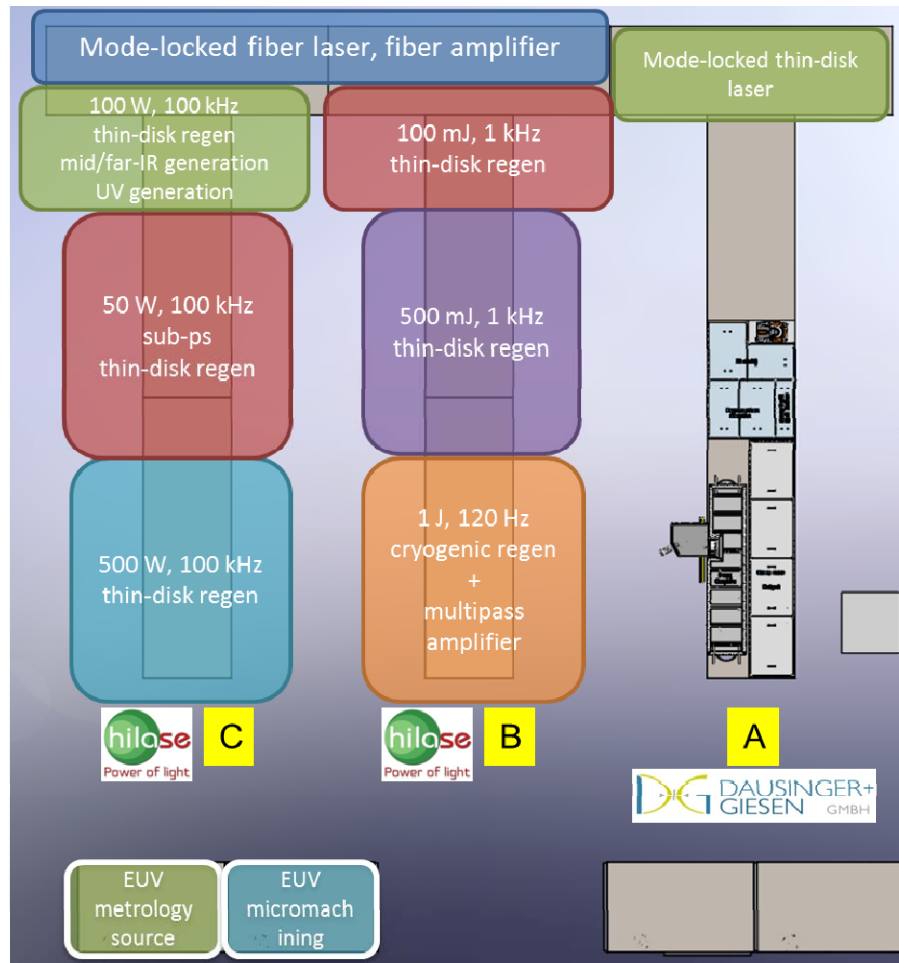
## Prague - HiLASE

## Application-oriented ps laser development



## Prague - HiLASE

## Thin-disk laser development laboratory



Clean room ISO 7 (10.000), 400 m2





## CNR – IFN Padova

### ■ EUV multilayer coatings at 13.5nm

Investigation of different materials to be used as protective capping-layers (Pt, Ir, Pd, B<sub>4</sub>C,...);  
Study of the damage mechanisms on ML optics induced by focused EUV beam at 13.5nm;

A.J. Corso, P. Zuppella, F. Barkusky, K. Mann, M. Müller, P. Nicolosi, M. Nardello, and M.G. Pelizzo, "Damage of multilayer optics with varying capping layers induced by focused extreme ultraviolet beam", *Journal of Applied Physics* 113(20), 203106 (2013).

### ■ ML structures at 6.67nm

Exploration of new materials couples (Pd/B<sub>4</sub>C, ...) with potential application in the new generation of EUVL;

A.J. Corso, P. Zuppella, D.L. Windt, M. Zangrando, and M.G. Pelizzo, "Extreme ultraviolet multilayer for the FERMI @ Elettra free electron laser beam transport system", *Optics Express* 20(7), 8006–8014 (2012).

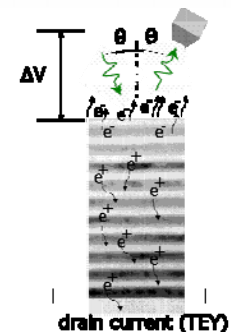
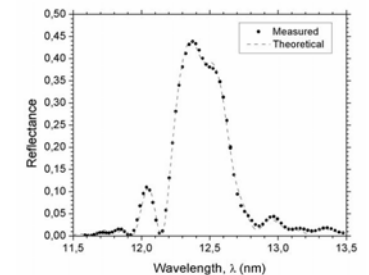
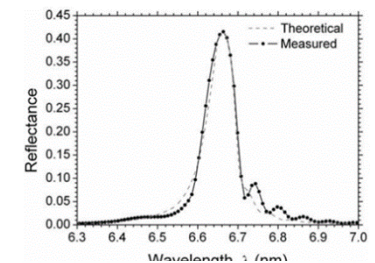
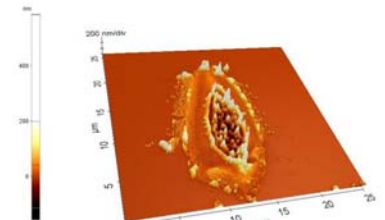
### ■ Design and realization of aperiodic structures and periodic blocks structures

The encouraging results achieved in the development of ML coatings for FEL applications can be successfully exploited also in EUVL applications;

A.J. Corso, P. Zuppella, E. Principi, E. Giangrisostomi, F. Bencivenga, A. Gessini, S. Zuccon, C. Masciovecchio, A. Giglia, S. Nannarone, and M.G. Pelizzo, "Broadband multilayer optics for ultrafast EUV absorption spectroscopy with free electron laser radiation", *Journal of Optics* 17(2), 025505 (2015).

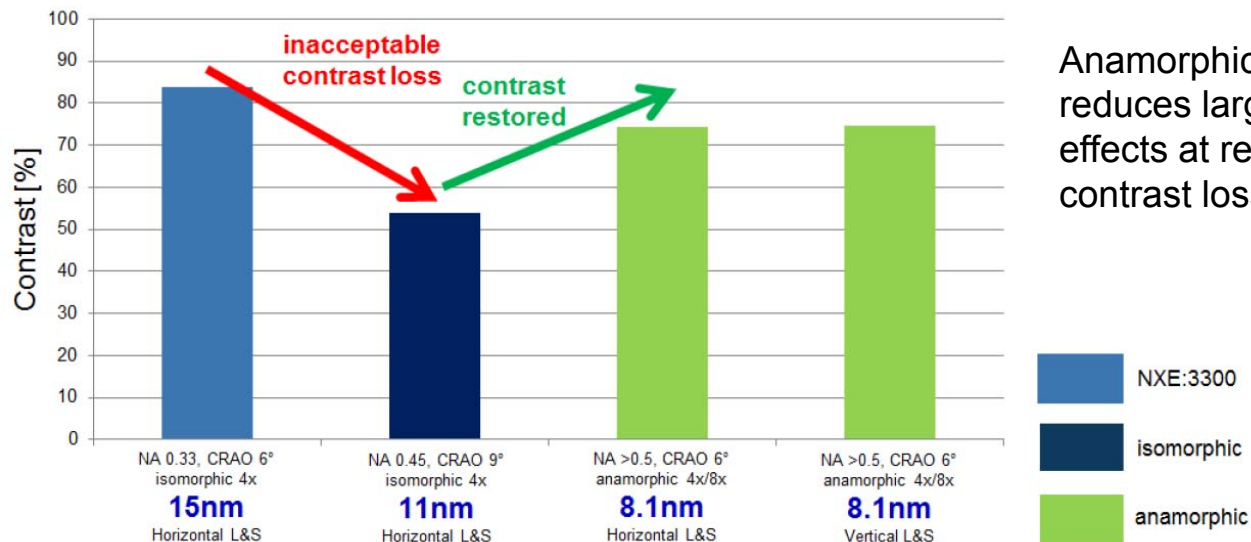
### ■ Characterization techniques based on photoemission measurements

A.J. Corso, P. Zuppella, S. Zuccon, and M.G. Pelizzo, "Phase characterization of multilayer coatings by photoemission measurements", *IEEE Photonics Technology Letters* 27(3), 241–244 (2015).

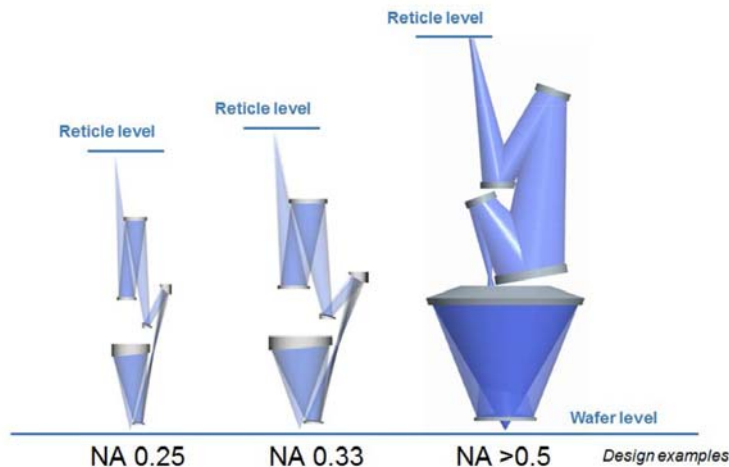


## Carl Zeiss SMT

- Extend the NA for EUV projection.
- Definition of system concept - shift to anamorphic imaging



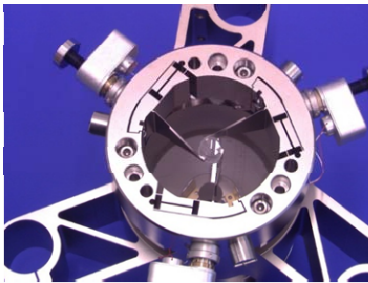
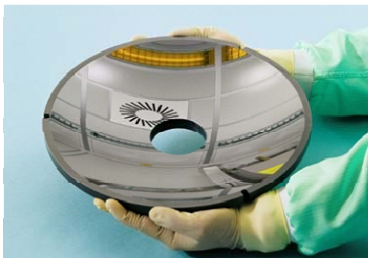
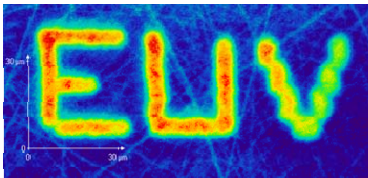
Anamorphic magnification of 4x / 8x reduces large angles / shadowing effects at reticle and helps to recover contrast loss.



Optical concept with a centrally obscured pupil has the potential to increase the transmission of the optical column

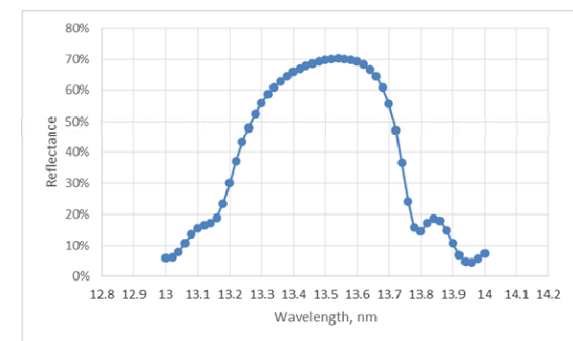


## optiX fab - Germany



- **History:** 1997: EUV multilayer development @ Fraunhofer IOF  
2009: Coating of first NXE:3100 collector mirror  
2012: Foundation of Fraunhofer IOF spin-off **optiX fab.**
- **Mission:** Fabrication of customized EUV optics and components for EUV lithography @ 13.5 nm and beyond, synchrotron and FEL beamlines, metrology, R&D applications, etc.
- **Focus:** EUV Collectors for LPP and DPP sources @ 13.5 nm
- **R&D:** Double-wavelength SPF for LPP collectors (SPIE 9422)
- **EUVR:**  $R = 70.2 \% @ 13.5 \text{ nm}$

# optiX fab.



## IMEC - Belgium

### 3<sup>RD</sup> GENERATION FULL FIELD SCANNER AT IMEC



2006 - 2011	2011 - 2015	2015-...
ASML Alpha-Demo tool Prototype 40nm → 27nm LS 0.25 NA	ASML NXE:3100 Pre-production 27nm, 22nm, 18nm LS 0.25 NA	ASML NXE:3300 Production 22, 16nm LS 0.33 NA

## IMEC - Belaium

**EUV litho**  
Fundamentals,  
Infrastructure building

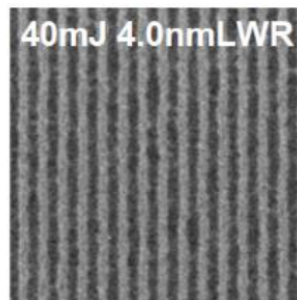
EUV resist and process

EUV mask defectivity

EUV scanner&source monitoring & characterization

EUV extendibility exploration

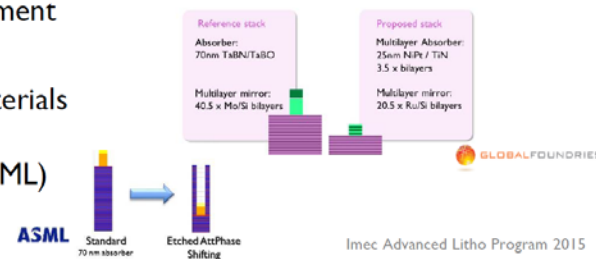
- ▶ Challenge :
  - meeting R(esolution), L(ine edge roughness) and S(ensitivity)
- ▶ Chemically amplified resists
- ▶ Alternative (metal containing) EUV resists



## IMEC - Belgium

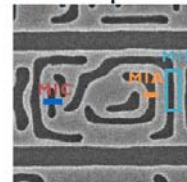
## EUV MASKS

- ▶ Challenge :
  - Defectivity (blank, reticle handling in fab)
  - Mask 3D effects
- ▶ Defectivity :
  - EIDEC ABI ML defect inspection – NXE:3300 printability
  - EUV pellicle development
- ▶ Mask 3D effects :
  - Alternative mask materials
  - Alternative mask architecture (etched ML)

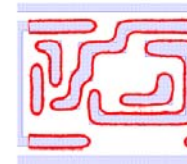
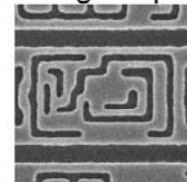


## EUV INSERTION

- ▶ NiO Metall etched in TiN hardmask
  - 193i Triple LE



## EUV single exposure



## ETH Zurich, Adlyte Switzerland

Research & Development of **droplet-based LPP sources** since 8 years

ALPS II Source as fully automated functioning system

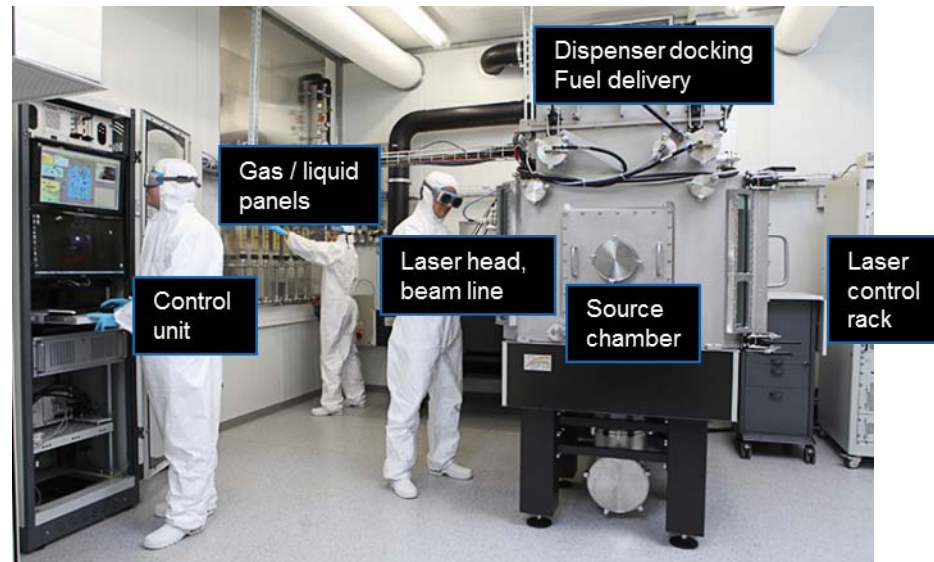
Main application in EUV photomask inspection

Droplet-based LPP, high brightness and pulse-to-pulse stability

Characterization of source emission and debris generation

Debris mitigated EUV collectors (NI & GI)

Cleanliness validated after IF



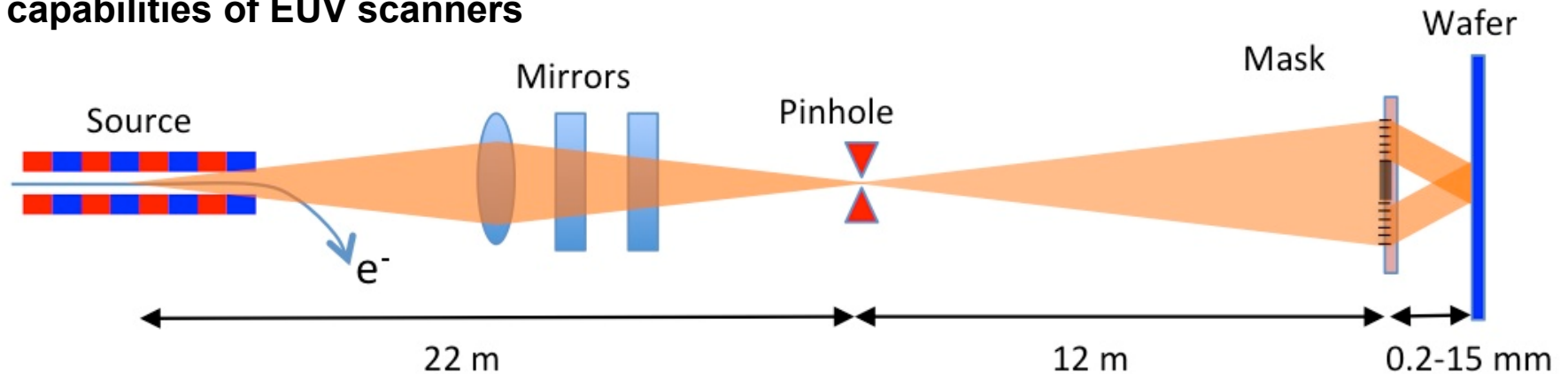
- Life-Time extension for 24/7 operation
- Long-term effort towards other wavelengths (Watt range)
- Source Productization by Adlyte and partners



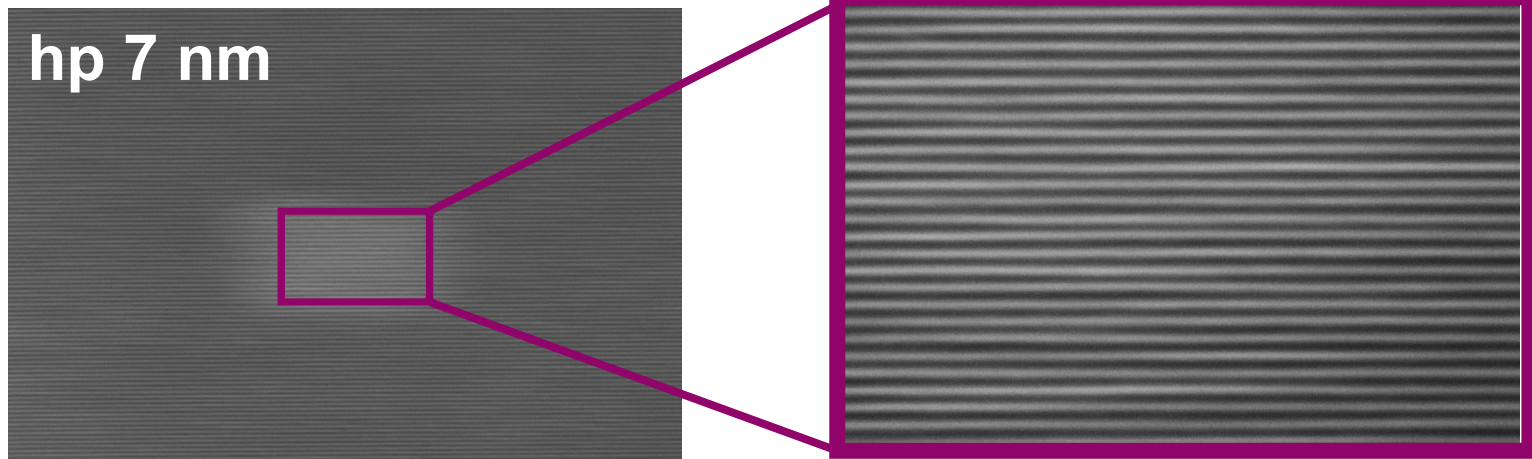
## PSI Switzerland

### XIL-II: EUV-IL @ PSI

Providing a state-of-the-art infrastructure for resist screening beyond the capabilities of EUV scanners



**Record resolution in photolithography**

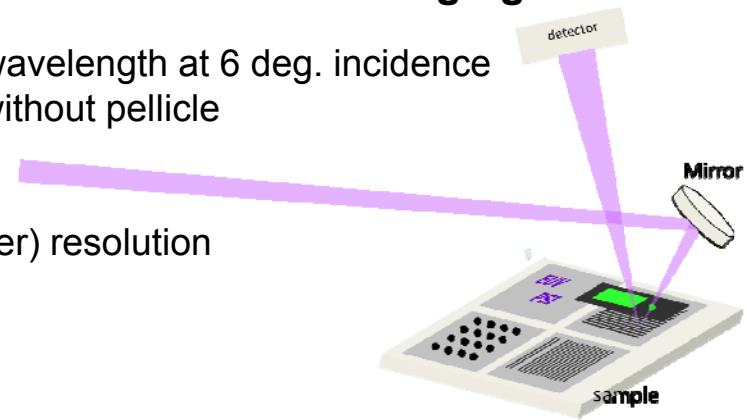




## PSI Switzerland

### Lensless EUV Mask metrology tool: Scanning coherent diffraction imaging

- Actinic EUV mask review and inspection tool: 13.5 nm wavelength at 6 deg. incidence
- EUV patterned/blank mask review and inspection with/without pellicle
- Amplitude & Phase mapping with 2D scans
- RESCAN 1: Dec. 2013: A demo tool with 20 nm (on wafer) resolution
- RESCAN 1+: July 2015: targeted for 10 nm resolution
- RESCAN 2: June 2016: a dedicated beamline
- RESCAN 3: Stand-alone tool



#### RESCAN 1

**Light Source :** Synchrotron (Undulator)  
**Flexible Wavelength :** 13.5nm, 6.7nm,  
**NA(X4) :** 0.25 – 0.35.  
**OAI :** 6, 8 degree  
**Stable** Narrow divergence, BW=1%  
**Probe** Zone plate, OSA, pinhole,  
 ML switching mirror set  
**Nav** 100 $\mu\text{m}^2$   
**Exposure time :** < 100 mSec

